Translucency and Strength of High-Translucency Monolithic Zirconium-Oxide Materials

Capt Todd D. Church

APPROVED:

Col Jeffrey P. Jessup

Col Villa L. Guillory

Kraig Vandewalle

Col (ret) Kraig S. Vandewalle

10 June 2016

Date

APPROVED:

Col Drew W. Fallis

Dean, Air Force Postgraduate Dental School

UNIFORMED SERVICES UNIVERSITY OF THE HEALTH SCIENCES
AIR FORCE POSTGRADUATE DENTAL SCHOOL
2450 Pepperrell Street
Lackland AFB Texas, 78236-5345
http://www.usuhs.mil

"The author hereby certifies that the use of any copyrighted material in the thesis/dissertation manuscript entitled:

"Translucency and Strength of High-Translucency
Monolithic Zirconium-Oxide Materials"

is appropriately acknowledged and, beyond brief excerpts, is with the permission of the copyright owner.

Todd D. Church, Capt, USAF, DC
AFPDS/AEGD-2
Uniformed Services University
12 May 2016

Translucency and Strength of High-Translucency Monolithic Zirconium-Oxide Materials

Abstract

Dental materials manufacturers have developed more translucent monolithic zirconium oxide restorations to combine the esthetics of all-ceramic restorations with the strength properties of zirconia. The purpose of this study was to evaluate the translucency and strength of new highly translucent monolithic zirconia ceramic materials. Four monolithic zirconium-oxide materials marketed as having high translucency (BruxZir Shaded 16 and BruxZir HT, Glidewell; Lava Plus, 3M ESPE; inCoris TZI C, Sirona) were compared to a high-translucency, lithium disilicate monolithic glass-ceramic material (IPS e.max CAD HT; Ivoclar Vivadent). To evaluate translucency, the materials were sectioned into 0.5-, 1-, 1.5-, and 2mm- thick specimens using a precision saw, sintered and polished according to the manufacturer's instructions (n=5). Translucency parameter was calculated using a spectrophotometer (VITA Easyshade, Vident) that measured L*, a*, and b* values. To evaluate flexural strength, the ceramic materials were sectioned using a precision saw to create beams with a final size of 4mm in width, 1.3mm in depth and 15mm in length after sintering in a ceramic oven (n=10). Each beam specimen was fractured using a universal testing machine with a three-point bending test device. Flexural modulus was determined from the slope of the linear region of the load-deflection curve using the analytical software (Instron). Data were examined with one-way ANOVAs with Tukey's post hoc tests. IPS e.max CAD had significantly higher translucency than the other materials at each thickness. In general, the translucencies of the zirconia materials were fairly similar at each thickness. However, at clinically relevant thicknesses, 1mm of BruxZir Shaded 16 and inCoris TZI C were more translucent than Lava Plus and BruxZir HT, but similar in translucency to the 1.5mm-thick specimens of IPS e.max CAD. Translucency significantly decreased for each material at each increase in thickness. The zirconia materials were similar in flexural strength and significantly greater than IPS e.max CAD. Flexural modulus was more variable. Of the

zirconia materials, BruxZir Shaded 16 had an overall better combination of translucency, strength and modulus.

Introduction

The desire to develop highly esthetic permanent restorations is not new. In 1886, Land developed the first all-ceramic crown, which was the most esthetic full veneer restorative material in dentistry for many years. In the mid-1900's, dental materials researchers began marketing and manufacturing metal-ceramic restorations which had strength and accuracy due to the cast metal, but also provided esthetically pleasing results because of the ceramic (Shillingburg et al., 1997). For years, dentists have used metal-ceramic crowns to provide their patients with strong, long lasting restorations, while also taking the patient's esthetic concerns into account. Yet, despite these favorable results, researchers have increased their studies of all-ceramic restorations in order to address the ever increasing esthetic demands and the desire for metal-free dentistry by patients (Heffernan et al., 2002).

The all-ceramic preference is based on an inherent translucency associated with these materials, which allows dentists and lab technicians to fabricate restorations that are similar to natural teeth (Kim et al., 2013). Translucency is one of the primary factors in controlling esthetics and it is critical in the selection of materials. All-ceramic systems have different compositions, microstructures, crystalline contents and phases which may influence the optical and strength properties. These ceramic systems can be divided into primarily glass-containing (e.g., feldspathic porcelain), reinforced glass (e.g., leucite and lithium disilicate), glass-infiltrated crystalline, and purely crystalline (e.g., zirconia and alumina) materials. However, an increase in the crystalline content to achieve greater strength often results in greater opacity (McLaren et al., 2009).

To provide high strength and improved esthetics, zirconium oxide has been used as a core material where porcelain is then fused to the outer surface. Zirconium oxide has been shown to

be more translucent than metal substructures when ceramic is fused to the outer surface (Spyropoulou et al., 2011). The outer porcelain is more translucent and allows the zirconia core material color to show (Al-Amleh et al., 2010). However, one common problem has involved an increase in the fracture rate of the veneered zirconium oxide compared to metal-ceramic crowns potentially caused by the mismatch of the coefficients of thermal expansion, surface grinding, inadequate core design, or overloading. To reduce the risk of veneering fracture and to simplify the procedure, manufacturers have recently marketed monolithic zirconia restorations (Lawson and Burgess, 2014).

Although relatively opaque, monolithic zirconium oxide crowns may have some advantages over metal- and zirconia-ceramic restorations. The zirconium oxide does not require as much tooth reduction compared to glass-based all-ceramic crowns, yet the flexural strength and fracture toughness of the monolithic material reduces the potential for chips and fractures associated with the use of veneering porcelain (Ilie and Stawarczyk, 2014). They can be milled and shaded prior to sintering, which is a much faster and less expensive process than ceramic veneering. Kim et al. (2013) found that yttria-stabilized tetragonal zirconia polycrystalline ceramics (3Y-TZP) can be made more translucent, while retaining their strength properties depending on sintering conditions. They concluded that less sintering time at the optimal temperature produces smaller grain sizes and enhanced translucency (Kim et al., 2013).

Most recently, dental manufacturers and laboratories have been marketing high-translucency monolithic zirconia restorative materials with claims of good esthetics and excellent strength properties. Glidewell (Newport Beach, CA), which produces a variety of BruxZir zirconia restorations, including BruxZir HT and BruxZir Shaded 16, claims their zirconium oxide materials offer improved optical properties due to unique colloidal and pressed processing techniques that differs from other processing methods (www.glidewelldental.com). BruxZir HT Milling Blanks are used for the production of full-contour zirconia crowns, bridges and implant crowns. The material is chemically and physically reprocessed to reduce zirconia

particle size and then shaped through a unique process (patent-pending). BruxZir HT requires staining or dipping to produce desired shades for a final restoration that purportedly exhibits maximum strength and translucent pearlescence. BruxZir Shaded 16 is a series of 16 pre-shaded pressed zirconia blanks that match all of the VITA Classical shades, with no color-dipping or staining required. It is marketed as a glaze-and-go system that ensures complete and consistent shade penetration (www.glidewelldental.com).

3M ESPE (St. Paul, MN), which produces the Lava Plus zirconium oxide material, asserts an improvement in their product's translucency by using a high-quality zirconia processing technique that reduces the number of impurities and structural defects. Lava Plus also contains less aluminum (0.1% wt) which reportedly reduces light scattering and improves translucency (www.multimedia.3m.com).

InCoris TZI C, from Sirona (Charlotte, NC), is marketed as pre-shaded millable zirconia blocks that do not require a separate dipping and drying step. According to Sirona, this pre-shaded, translucent zirconium oxide accelerates the production of esthetically pleasing fully anatomical restorations while maintaining high strength, resistance to corrosion, good biological compatibility and offering 10 pre-dyed VITA shades (A1-A4; B2; B3; C2; C3; D3) (www.sirona.com).

With claims of greater translucency without a reduction in strength properties, these monolithic zirconia-ceramic materials attempt to fulfill the desires of both patients and doctors. Limited research has been published evaluating the translucency and strength properties of these recently introduced high-translucency zirconia materials. The purpose of this study was to evaluate the translucency parameter and flexural strength and modulus of the recently marketed monolithic zirconia-ceramic materials compared to a popular lithium disilicate glass-ceramic material. The first null hypothesis tested for this study was there would be no difference in translucency parameter based on ceramic material or thickness. The second null hypothesis

was there would be no difference in flexural strength or flexural modulus between the ceramic materials.

Materials and Methods

Four monolithic zirconia oxide materials marketed as having high translucency (BruxZir Shaded 16, BruxZir HT, Lava Plus, and inCoris TZI C) were compared to a high-translucency, lithium disilicate glass-ceramic material (IPS e.max CAD HT; Ivoclar Vivadent, Amherst, NY). The BruxZir Shaded 16, inCoris TZI C and IPS e.max CAD HT blocks were all preshaded (A2) and did not require immersion in dye solution.

Translucency was evaluated by determining the translucency parameter of the ceramic materials. The ceramic materials were sectioned into 0.5, 1.0, 1.5, and 2.0 mm thick specimens using a precision saw (Isomet 5000, Buehler, Lake Bluff, IL). After sectioning, the specimens were prepared according to each manufacturer's specifications prior to sintering in a high-temperature furnace (inFire HTC, Sirona).

The Lava Plus specimens were shaded according to manufacturer's instructions prior to sintering. An immersion container was selected that was dry, clean, and free of residual dyeing liquid. A bottle of Lava Plus Zirconia Dyeing Liquid shade A2 was shaken before use and the immersion container was subsequently filled. The specimens were placed in the dyeing liquid for 2 minutes. Residual dyeing liquid was removed from each specimen using an absorbent paper towel and then allowed to air dry. Following the shading procedure, each specimen was sintered according to the manufacturer's specifications in a high-temperature furnace.

The BruxZir HT specimens were shaded according to manufacturer's instructions. A bottle of BruxZir Coloring Liquid shade A2 was selected and shaken prior to use. Coloring liquid was poured into the clean and dry immersion container to cover the specimens by at least 1 mm. The specimens were cleaned, dried, placed in the coloring liquid and allowed to soak for 15 minutes. Each specimen was carefully removed and placed on a dry, clean surface and air-

dried. Each specimen was placed under a light and allowed to dry. Following the shading procedure, each specimen was sintered according manufacturer's specifications in the high-temperature furnace.

Prior to translucency measurements, the thickness of the specimens was measured with a digital caliper (GA182, Grobet Vigor, Carlstadt, NJ), polished with 400- and 600-grit silicone-carbide sandpaper (Sandblaster Pro, 3M), and deemed acceptable if within ± 0.05 mm of the thickness for that group. A pilot study was conducted to determine initial specimen thickness before sintering. Five specimens were prepared per thickness of material. Transmission parameter was determined using a dental spectrophotometer (VITA Easyshade Compact, Vident, Yorba Linda, CA) in single-tooth mode using techniques outlined in a recent study by Della Bona et al. (2014). The tip of the spectrophotometer was held in contact with the surface of the specimen. Three measurements of L* a* and b* were recorded for each specimen. In the color space, L* indicates lightness, the a* coordinate represents the red/green range and the b* coordinate represents the yellow/blue range. Translucency parameter (TP) was determined by calculating the color difference between readings against black (B) and white (W) backgrounds for the same specimen according to the following equation: $TP = ((L^*B – L^*W)^2 + (a^*B – a^*W)^2 + (b^*B – b^*W)^2)^{1/2}$. The greater the translucency parameter, the greater the translucency of the specimen. A mean and standard deviation was determined for each of the ceramic materials. Data were analyzed with a two-way ANOVA to evaluate the effect of ceramic type and thickness on translucency parameter (alpha=0.05).

Flexural strength testing was completed following the international standard on ceramic materials (ISO Standard 6872, Dentistry – Ceramic Materials, 2008). Ten specimens were prepared for each ceramic material. To prepare each beam specimen, the ceramic materials were sectioned using the precision saw. The final size of the beam specimens was 4mm in width, 1.3mm in depth and 15mm in length. A pilot study was conducted to determine the size of the sectioned beam specimens necessary to result in the final beam size after sintering of

each ceramic block material in a ceramic oven as before. Each beam specimen was fractured using a universal testing machine (Model 5543, Instron, Canton, MA). Each specimen was placed on a three-point bending test device, which was constructed with a 13mm span length between the supporting rods, with the central load applied with a head diameter of 2mm at a crosshead speed of 1.0 mm/min. The flexural strength was obtained using the expression: $FS = 3Fl / 2bd^2$ where F is the loading force at the fracture point, l is the length of the support span (13 mm), b is the width, and d is the depth. Measurements were made using the electronic digital caliper. Flexural modulus was determined from the slope of the linear region of the load-deflection curve using the analytical software (Bluehill, Instron). The mean and standard deviation were calculated for each of the ceramic materials. The data were examined with a one-way ANOVA with Tukey's post hoc test to evaluate the effect of ceramic type on flexural strength or flexural modulus (alpha = 0.05).

Results

For translucency parameter, the two-way ANOVA found a significant difference based on ceramic material ($p<0.001$) and thickness ($p<0.001$), but there were significant interactions ($p>0.05$). The data were further analyzed with one-way ANOVAs and Tukey's post hoc tests to evaluate the effect of ceramic material on translucency parameter per thickness and the effect of thickness on translucency parameter per ceramic material. A Bonferroni correction was applied because multiple comparison tests were completed (alpha=0.006). Significant differences in translucency parameter were found between groups based on material or thickness ($p<0.006$). IPS e.max CAD had significantly higher translucency than the other zirconia materials at each thickness. See Table 1.

Translucency Parameter (mean, st dev)				
Ceramic	0.5 mm	1.0 mm	1.5 mm	2.0 mm
e.max CAD HT	34.2 (0.5) Aa	23.2 (0.4) Ba	17.9 (0.2) Ca	13.3 (0.3) Da
BruxZir Shaded 16	26.3 (0.8) Ab	18.2 (0.3) Bb	11.7 (0.7) Cb	7.8 (0.2) Db
inCoris TZI C	25.9 (1.1) Ab	17.5 (0.7) Bb	10.5 (0.5) Cbc	6.3 (0.4) Dc
Lava Plus	25.1 (0.7) Abc	15.7 (0.4) Bc	9.7 (0.5) Cc	7.0 (0.5) Dbc
BruxZir HT	23.2 (0.8) Ac	14.6 (0.5) Bc	9.2 (1.0) Cc	7.0 (0.3) Dbc

Groups with the same upper case letter per row or lower case letter per column are not significantly different (p>0.006).

Table 1: Translucency parameter for each of the five ceramic materials at various thicknesses.

Significant differences in flexural strength or flexural modulus were found between groups ($p<0.001$). IPS e.max CAD had significantly lower flexural strength than the zirconia materials, which were not significantly different from each other. IPS e.max CAD and inCoris TZI C had significantly lower flexural modulus while BruxZir Shaded 16 had significantly higher modulus. See Table 2.

Ceramic	Flexural Strength (MPa, st dev)	Flexural Modulus (GPa, st dev)
e.max CAD HT	387.4 (51.9) b	147.7 (19.1) c
BruxZir Shaded 16	921.7 (112.0) a	290.8 (15.7) a
inCoris TZI C	855.2 (119.7) a	132. 2 (11.4) c
Lava Plus	880.0 (156.1) a	270.1 (16.8) b
BruxZir HT	953.9 (86.7) a	270.1 (16.8) b

Groups with the same lower case letter per column are not significantly different (p>0.05).

Table 2: Flexural strength and modulus for each of the five ceramic materials.

Discussion

The first null hypothesis was rejected. Differences were found in the translucency parameter based on type of ceramic material or thickness. IPS e.max CAD had significantly higher translucency than the zirconia materials at each thickness. Corresponding results were shown by Baldissara et al., (2010), who found that the lithium disilicate glass ceramic showed

significantly greater translucency than zirconia-based core materials. In this study, the translucencies of the zirconia materials were fairly similar at each thickness. However, translucency significantly decreased for each material at each increase in thickness. In two recent studies involving the translucency parameter of zirconia materials, the authors determined that as the thicknesses of sintered zirconia specimens increased, the translucency decreased significantly (Bunek et al., 2014; Sulaiman et al., 2015).

Translucency is one of the primary factors in controlling esthetics and it is critical in the selection of dental materials (Della Bona et al., 2014). Yet, there are other factors that must be taken into consideration such as underlying tooth structure, cement opacity and shade, necessary thickness of the restoration and the location of tooth in the arch to be restored. However, knowledge of a material's translucency allows for the fabrication of natural-looking, esthetic restorations that mimic the transition between the higher opacity of dentin and the relative translucency of enamel. One of the disadvantages of zirconia restorations is the relative opaque nature of the material when compared to other ceramic materials due to the size of the crystalline particles, leading to greater light scattering and less translucency because less light is transmitting through the material (Sulaiman et al., 2015). The current study evaluated zirconia materials marketed as being highly translucent and compared these to a commonly used high translucency lithium disilicate material (IPS e.max CAD HT).

Ivoclar Vivadent, the manufacturer of IPS e.max CAD, advises that the material should not be used for posterior full-coverage crowns with less than 1.5 mm in thickness/occlusal reduction due to the functional stress it must withstand (www.ivoclarvivadent.us). On the other hand, the zirconium oxide materials used in the current study have a minimal thickness recommendation as low as 0.5 millimeters as reported by the manufacturer (www.bruxzir.com, www.multimedia.3m.com, www.sirona.com).

When the manufacturer's recommendations are considered and the translucency parameter at each minimal thickness is compared, the results are more comparable (see Table

1 and Figure 1). With 1mm of thickness, BruxZir Shaded 16 (18.2 ± 0.3) and inCoris TZI C (17.5 ± 0.7) were more translucent than Lava Plus (15.7 ± 0.4) and BruxZir HT (14.6 ± 0.5), but similar in translucency to the 1.5mm-thick specimens of IPS e.max CAD (17.9 ± 0.2). At 0.5mm thickness, BruxZir Shaded 16 (26.3 ± 0.8), inCoris TZI C (25.9 ± 1.1), Lava Plus (25.1 ± 0.7) and BruxZir HT (23.2 ± 0.8) were less translucent than IPS e.max CAD (34.2 ± 0.5), but more translucent that IPS e.max CAD at the recommended 1.5 mm thickness (17.9 ± 0.2). At clinically recommended thicknesses, the translucency parameters of the newly marketed translucent zirconia materials were not only similar to those of the lithium disilicate ceramic material, but also comparable to the translucency parameters reported for 1mm of dentin (16.4) or enamel (18.7) (Yu et al., 2009). In terms of translucency, the studied zirconia could satisfactorily replace dentin within a restoration, but in order to produce a clinically acceptable match, it is necessary to carefully adjust the color of these systems (Pecho et al., 2012).

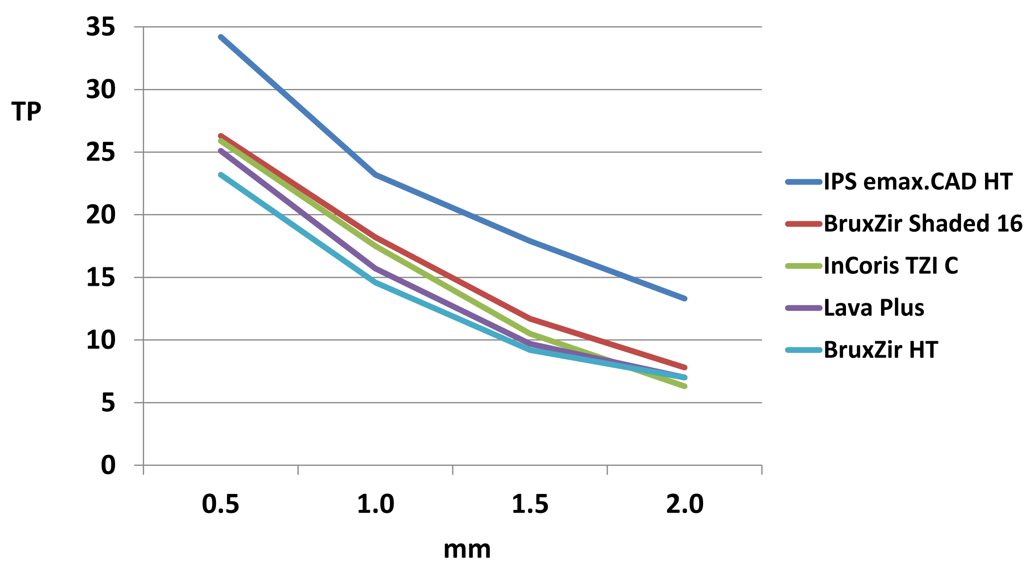

Figure 1: Translucency parameter of each of the five ceramic materials at various thicknesses

Two main techniques are available for coloring. Zirconia metal oxides are added to the Y-TZP powder or the milled restoration is dipped in chloride solutions before sintering (Kurtulmus-

Yilmaz and Ulusoy, 2014). The coloring method may affect the intensity of the shade and the translucency of the zirconia. A laboratory study by Tuncel et al., (2013) found that coloring liquids decreased the translucency of zirconia frameworks. This agrees with the results of this study which found that the translucency of the dipped zirconia (BruxZir HT) was significantly less than the translucency of the pre-colored zirconia (BruxZir Shaded 16). A study by Kurtulmus-Yilmaz and Ulusoy (2014), however, found that coloring liquid did not have a significant effect on translucency of zirconia cores. Instead, darker shades of the precolored zirconia were found to have less translucency.

An advantage to polycrystalline ceramic restorations is that due to their high strength properties they can be cemented using a variety of luting agents including conventional cements. However, for preparations having limited retentive features, the use of resin cements, in particular dual-cure resin cements, may be advisable to increase adhesion. Yet, studies have shown that light activation of dual-cure resin cement produces higher mechanical properties of the cement rather than relying on self-cure activation alone (Ilie and Stawarczyk, 2014). Thus, the translucency of zirconia ceramic materials may play a role in the adhesive strength of the restoration when a dual-cure resin cement is utilized.

The use of zirconia materials has increased in recent years in part because of its superior strength properties when compared to other ceramic materials. However, to achieve a good esthetic outcome, porcelain may be veneered to the outer surface of the zirconia. A commonly encountered problem from these kinds of restorations involves the fracture of the porcelain from the underlying zirconia material. The clinical concern with fractures is one of the main reasons monolithic zirconia restorations have become popular and manufacturers have tried to develop more translucent zirconia that can be used in more clinical situations (Lawson and Burgess, 2014). In this study, differences were found in flexural strength and modulus based on the type of ceramic material and therefore, the second null hypothesis was rejected. Flexural strength estimates a material's resistance under bending, which is a common form of stress in prosthetic

dentistry (Homaei et al., 2016). The results of this study found that the zirconia materials were similar in flexural strength and significantly greater than IPS e.max CAD. A recent study by Homaei et al. (2016) found a similar mean flexural strength of a zirconium oxide framework material (Cercon, Dentsply, York, PA) of 886.9 ± 80.2 MPa and IPS e.max CAD of 356.7 ± 59.6 MPa.

Differences between groups were also found in flexural modulus, but the results were more variable. The flexural moduli of the majority of the zirconia materials tested were nearly double that of the lithium disilicate material tested, which also agrees with a recent laboratory study (Homaei et al., 2016). These findings illustrated that the force necessary to deform the zirconia is much greater than that of commonly used glass-ceramic materials. Because of the many variables related to bite forces in the human dentition including off-axis loading and fatigue over time, intraoral situations can only be estimated by *in vitro* testing. However, there are many situations where a strong material maybe indicated such as with a patient with a history of fractured restorations or bruxism.

The highly translucent zirconia materials were shown in the current study to be as translucent as lithium disilicate at clinically recommended thicknesses and to be far stronger when compared at similar thicknesses, which indicates, that restorations using these materials may have a promising future. Of the zirconia materials tested, BruxZir Shaded 16 had an overall better combination of translucency, strength and modulus. However, more studies are necessary to evaluate the long-term cyclic-fatigue resistance and wear against opposing dentition of these new high-translucency zirconia materials.

Conclusions

Within the limitations of the current study the following conclusions can be made:

- At similar thicknesses, highly translucent zirconium-oxide materials are not as translucent as lithium disilicate.

- At clinically recommended thicknesses, highly translucent zirconia materials are as translucent as lithium disilicate.
- The flexural modulus and flexural strength of highly translucent zirconia materials is significantly higher than those of lithium disilicate.

Disclaimer

The opinions or assertions contained herein are the private ones of the author(s) and are not to be construed as official or reflecting the view of the DoD or the USUHS. The authors do not have any financial interest in the companies whose materials are discussed in this article.

References

Al-Amleh B, Lyons K, Swain M. Clinical trials in zirconia: a systematic review. J Oral Rehab 2010;37:641–652.

Baldissara P, Llukacej A, Ciocca L, Valandro FL, Scotti R. Translucency of zirconia copings made with different CAD/CAM systems. J Prosthet Dent. 2010;104(1):6-12.

Bunek SS, Baumann A, Yapp R, Paravina RD, Powers JM. Translucency of CAD/CAM ceramics. The Dental Advisor: May 2014; number 59.

Della Bona A, Nogueira AD, Pecho OE. Optical properties of CAD-CAM ceramic systems. J Dent 2014;42:1202-1209.

Heffernan M, Aquilino S, Diaz-Arnold A, Haselton D, Stanford C, Vargas M. Relative translucency of six all-ceramic systems. Part I: Core materials. J Prosthet Dent 2002;88:4-9.

Heffernan M, Aquilino S, Diaz-Arnold A, Haselton D, Stanford C, Vargas M. Relative translucency of six all-ceramic systems. Part II: Core and veneer materials. J Prosthet Dent 2002;88:10-15.

Homaei E, Farhangdoost K, Tsoi JK, Matinlinna JP, Pow EH. Static and fatigue mechanical behavior of three dental CAD/CAM ceramics. J Mech Behav Biomed Mater. 2016 Feb 2;59:304-313.

Ilie N, Stawarczyk B. Quantification of the amount of light passing through zirconia: The effect of material shade, thickness, and curing conditions. J Dent 2014;42:684-690.

International Organization for Standardization ISO/TS 10650. Dental equipment—powered polymerization activators. International Organization for Standardization: Geneva, Switzerland; 1999.

ISO Standard 6872, Dentistry – Ceramic Materials 2008;(E):8-10.

Kim M, Ahn J, Kim J, Kim H, Kim W. The effects of sintering conditions of dental zirconia ceramics on the grain size and translucency. J Adv Prosthodont 2013;5:161-166.

Kurtulmus-Yilmaz S, Ulusoy M. Comparison of the translucency of shaded zirconia all-ceramic systems. J Adv Prosthodont. 2014 Oct;6(5):415-422.

Lawson NC, Burgess JO. Dental ceramics: a current review. Compend Contin Educ Dent 2014;35(3):161-166.

McLaren EA, Cao PT. Ceramics in Dentistry—Part I: Classes of Materials. Inside Dentistry 2009;11:94-104.

Pecho OE, Ghinea R, Ionescu AM, Cardona Jde L, Paravina RD, Pérez Mdel M. Color and translucency of zirconia ceramics, human dentine and bovine dentine. J Dent 2012 Dec;40 Suppl 2:e34-40.

Shillingburg H, Hobo S, Whitsett L, Jacobi R, Brackett S. Fundamental of fixed prosthodontics. 3rd ed. Chicago: Quintessence Books; 1997:433, 455.

Sulaiman TA, Abdulmajeed AA, Donovan TE, Ritter AV, Vallittu PK, Narhi TO, Lassila LV. Optical properties and light irradiance of monolithic zirconia at variable thicknesses. Dent Mater. 2015;31:10:1180-1187.

Spyropoulou P, Giroux E, Razzoog M, Duff R. Translucency of shaded zirconia core material. J Prosthet Dent 2011;105:304-307.

Tuncel I, Eroglu E, Sari T, Usumez A. The effect of coloring liquids on the translucency of zirconia framework. J Adv Prosthodont. 2013 Nov;5(4):448-451.

www.bruxzir.com. Available at: "http://www.bruxzir.com/dental-zirconia/technical-information/". Accessed April 13, 2016.

www.glidewelldental.com. Available at: "www.glidewelldental.com/dentist/inclusive/volume2-4/zirconia-esthetics.aspx". Accessed Oct. 9, 2014.

www.ivoclarvivadent.us. Available at: “www.ivoclarvivadent.us/en-us/download-center/scientific-documentation/#E”. Accessed March 5, 2016.

www.multimedia.3m.com. Available at: http://multimedia.3m.com/mws/mediawebserver?mwsId=66666UgxGCuNyXTtoXTXL8T6EVtQEcuZgVs6EVs6E666666--&fn=146123M_ESP_2S_Translucency_rz.p. Accessed Oct. 9, 2014.

Yu B, Ahn JS, Lee YK. Measurement of translucency of tooth enamel and dentin. Acta Odontol Scand. 2009;67:57–64.